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A Differential Modulation Scheme for Multihop Amplify-and-Forward Relaying Systems

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Abstract

In this paper, we propose a new differential modulation scheme for multihop communication systems with amplify-and-forward relaying. In the proposed scheme, each transmitted frame is divided into several blocks, and each block consists of one reference symbol and several normal symbols. The reference symbol in each block is differentially encoded based on the previous reference symbol, while the normal symbols are differentially encoded based on the reference symbol in the same block. The main advantage of the proposed scheme is allowing power allocation among the reference symbol and normal symbols to improve the system performance. Numeric results show that the gap between the proposed differential modulation scheme with a block length of 256 and the coherent receiver with perfect channel state information (CSI) is within 0.5dB in slow fading channels.

Keywords: *Multihop transmissions; amplify-and-forward; differential modulation*

1. Introduction

Recently, there has been growing interest in the concept of multihop relaying in wireless networks such as next generation cellular networks, ad hoc networks and broadband fixed wireless networks. Benefits of

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multihop communications include overcoming channel impairments, attaining broader coverage, and reduction of transmit power, and so on [1]-[2].

Decode-and-Forward (DF) and Amplify-and-Forward (AF) are two basic relaying protocols. The performance of multihop relayed transmission with AF relaying has been studied in [3] and [4] in terms of outage probability and average bit error rate (BER). However, most of previous works assume that perfect CSI is available at the receiver. In a practical system, these channels must be estimated at the receiver for coherent detection. Differential modulation is a well known technique to avoid channel estimation, and can be applied to dual-hop and multihop communication systems as well. In [5] and [6], the authors propose differential modulation for dual-hop networks with DF and AF relaying protocol. However, as in point-to-point systems, the differential modulation scheme in dual-hop networks also suffers from the 3dB performance loss as compared with the coherent receiver.

In this paper, we propose a generalized differential modulation (GDM) scheme for multihop transmissions with amplify-and-forward relaying. In the proposed scheme, each transmitted frame at the source is divided into several blocks. The first symbol in each block is referred to as reference symbol, and the other symbols in each block are normal symbols. The reference symbol in each block is differentially encoded based on the previous reference symbol, while the normal symbols are differentially encoded based on the reference symbol in the same block. We also investigate the power allocation among the reference symbol and the normal symbols to maximize the output signal-to-noise ratio (SNR) at the destination.

2. System Model

We consider a K-hop wireless communication system with one source T_0, one destination T_K, and K-1 relays denoted by T_k, k=1,2,…,K-1, as shown in Fig.1. The AF relaying protocol is employed, in which the relays scale the received signal and then forward it to the next relay. We consider a time-division multiplexing (TDM) system that the source and relays transmit at different time slots.

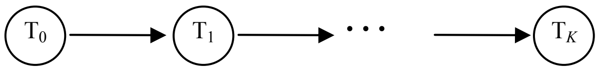


Fig.1. a K-hop communication system.

2.1. Proposed differential modulation

A sequence of phase-shift keying (PSK) symbols $S(n)$, n = 1,2,…,N, are to be transmitted from T_0 to T_K with the help of these relays. For the conventional differential modulation (CDM), the information symbols $S(n)$ at the source are differentially encoded as

$$x_0(n) = x_0(n-1)S(n), \quad n = 1,2,...,N, \tag{1}$$

where $x_0(n)$ denotes the signal to be transmitted at time n and $x_0(0)$ is the initial reference symbol. After differential encoding, there are (N+1) symbols in each transmitted frame. In the proposed scheme, these (N+1) symbols are divided into B blocks, each block with Q symbols. Without loss of generality, we assume (N+1)=BQ. The first symbol in each block, $x_0(bQ)$, b=0,1,…,B-1, is referred to as reference symbol. The other symbols, $x_0(bQ+q)$, b=0,1,…,B-1,q=1,2,…,Q-1, are referred to as normal symbols. The reference symbol in the bth block is differentially encoded based on the reference symbol in the previous block

$$x_0(bQ) = x_0((b-1)Q)S(bQ)\,,\; b = 1,2,...,B-1\,, \tag{2}$$

where $x_0(0)$ is the initial reference symbol with a transmit power of $P_{0,1}$, which is known by the receiver as in conventional differential modulation. On the other hand, the normal symbols in the bth block are encoded based on the reference symbol in this block:

$$x_0(bQ+q) = \sqrt{\frac{P_{0,2}}{P_{0,1}}}x_0(bQ)S(bQ+q)\,,\;\; b = 0,1,...,B-1\,,\;\; q = 1,2,...,Q-1\,. \tag{3}$$

To ensure an average transmit power of P_0 at T_0, $P_{0,1}$ and $P_{0,2}$ should satisfy $P_{0,1}+(Q-1)P_{0,2} = Q P_0$.

2.2. Multihop transmission

Let $h_k(n)$ be the channel coefficient of the kth hop from the terminal T_{k-1} to T_k at time n. The received signal at T_k can be expressed as

$$y_k(n) = h_k(n)x_{k-1}(n) + z_k(n)\,,\; n = 0,1,...,N\,, \tag{4}$$

where $x_{k-1}(n)$ is the transmit signal of T_{k-1} and $z_k(n)$ denotes the additive white Gaussian noise (AWGN) at T_k with a variance of N_0. In the considered AF protocol, each relay terminal scales the received signal and forwards it to the next terminal. This linear operation can be expressed as $x_k(n)=A_k(n)\, y_k(n)$, where $A_k(n)$ is the amplification factor. When perfect CSI is available at T_k, $A_k(n)$ is chosen as

$$A_k(n) = \sqrt{\frac{P_k}{|\,h_k(n)|^2\; P_{k-1} + N_0}} \tag{5}$$

where P_k is the average transmit power of T_k. After propagating through N hops, the received signal at the destination T_K can be expressed as

$$y_K(n) = h(n)x_0(n) + z(n) \tag{6}$$

where $h(n) = \prod_{k=1}^{K-1} A_k(n) \prod_{k=1}^{K} h_k(n)$ and $z(n) = z_K(n) + \sum_{k=1}^{K-1} z_k(n)\left(\prod_{l=k+1}^{K} A_{l-1}h_l(n)\right)$.

3. Differential Detection

The detection of reference symbols and normal symbols are similar. In the following, we only show how to detect the reference symbols. We assume slow fading channels that the fading coefficients keep approximately unchanged within one block duration. Then the received reference symbol in the bth block can be expressed as

$$y_K(bQ) = y_K((b-1)Q)S(bQ) + w(bQ) \tag{7}$$

where $w(bQ)=z(bQ)-S(bQ)z((b-1)Q)$.According to the differential modulation rule in (2), the differential detection of the reference symbols is performed as

$$\tilde{y}(bQ) = y_K^{\,*}((b-1)Q)\,y_K(bQ) \tag{8}$$

After some manipulations, (8) can be written as

$$y^{'}(bQ) = \left|h(bQ)x_0((b-1)Q)\right|^2 S(bQ) + w^{'}(bQ) \tag{9}$$

where $w'(bQ)$ is the residue interference-plus-noise. From (9), it is easy to show that the output SNR is

$$\gamma(bQ) = \frac{|h(bQ)|^2 P_{0,1}}{2\sigma_z^{\,2}(bQ)} = \frac{P_{0,1}}{2P_0}\left[\prod_{k=1}^{K}\left(1+\frac{1}{\gamma_k(bQ)}\right)-1\right]^{-1} \quad (10)$$

where $\gamma_k(n)=|h_k(n)|^2 P_{k-1}/N_0$.Similarly, the output SNR of the qth normal symbol in the bth block is

$$\gamma(bQ+q) = \frac{P_{0,1}P_{0,2}\,|h(bQ+q)|^2}{(P_{0,1}+P_{0,2})\sigma_z^{\,2}(bQ+q)} = \frac{P_{0,1}P_{0,2}}{P_0(P_{0,1}+P_{0,2})}\left[\prod_{k=1}^{K}\left(1+\frac{1}{\gamma_k(bQ+q)}\right)-1\right]^{-1} \quad (11)$$

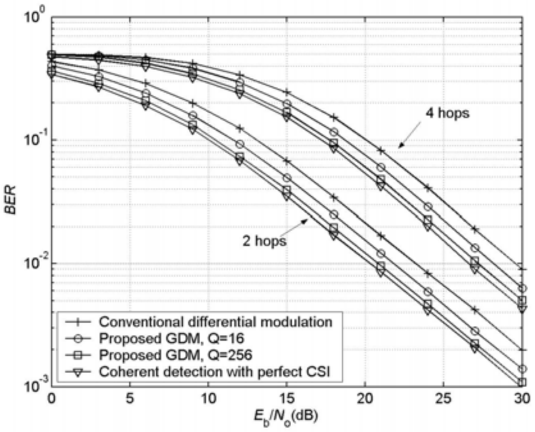
To maximize the output SNR, the optimal power allocation factors can be determined as

$$P_{0,1} = \frac{QP_0}{1+\sqrt{Q-1}}, \quad P_{0,2} = \frac{QP_0}{Q-1+\sqrt{Q-1}}. \quad (12)$$

4. Simulation Results

In this section, we present simulation results for wireless relay network with amplify-and-forward relaying and DQPSK modulation. The source and the relays have the same average transmit power. We plot the performance curves in terms of average BER versus E_b/N_0. During simulation, we assume i.i.d. fading channels with unit channel gains. The channel coefficients are generated according to the Clarke's model [7].

Fig.2(a) shows the average BER performance of multihop relayed systems with 2 and 4 hops in slow fading channels. The normalized Doppler frequency shift is set to be $f_D T_s=10^{-5}$, where f_D is the Doppler frequency and $T_s$is the symbol duration. We also plot the performance of conventional differential modulation and that of coherent detection with perfect CSI for comparison. It is clear that there is a 3dB performance gap between CDM and the coherent counterpart. While the performance of the proposed scheme improves as the block length increases and outperforms CDM. For a block length of 16, there is a 1.3dB performance gain as compared with CDM at the BER of 10^{-2} in a 2-hop system. When the block length increases to be 256, the gap between the proposed GDM and the coherent detection reduces to be 0.5dB only.



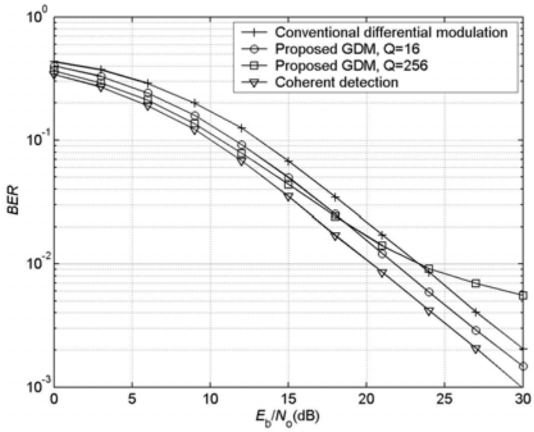


Fig.2. BER performance of the proposed GDM scheme (a) slow fading channels (b) fast fading channels.

The BER of proposed GDM scheme in a 2-hop system over fast fading channels is shown in Fig. 2(b). The normalized Doppler frequency shift is set to be $f_D T_s=10^{-4}$. From the figure we can see that the performance of the system with larger Q deteriorates in the high SNR region. This is due to the fact that the GDM scheme requires that the channel coefficients remain approximately invariant during the block duration. As a result, the system with larger block length is more sensitive to the Doppler frequency shift. However, the proposed GDM scheme with Q=16 still outperform the conventional differential modulation scheme even in fast fading channels.

5. Conclusion

A new differential modulation scheme for wireless multihop communication systems with amplify-and-forward relaying was proposed. With optimal power allocation among the reference symbols and normal symbols, the proposed scheme with a block length of 256 provided a 2.5dB performance improvement at a BER of 10^{-2} over the conventional scheme in slow fading channels. This novel differential modulation scheme can also be readily extended to multihop relayed transmissions with decode-and-forward relaying.

Acknowledgements

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